

# **MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR**

Technical Progress Report

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## MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

### ABSTRACT

This project was awarded under U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) Program Solicitation DE-PS26-00NT40769 and specifically addresses Technical Topical Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Plant operated by Otter Tail Power Company, host for the field testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid*<sup>™</sup> filter by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

The objective of the three-task project is to demonstrate 90% total mercury control in the AHPC at a lower cost than current mercury control estimates. The approach includes bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, pilot-scale testing on a coal-fired combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses, and field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

This project, if successful, will demonstrate at the pilot-scale level a technology that would provide a cost-effective technique to accomplish control of mercury emissions and, at the same time, greatly enhance fine particulate collection efficiency. The technology can be used to retrofit systems currently employing inefficient ESP technology as well as for new construction, thereby providing a solution to a large segment of the U.S. utility industry as well as other industries requiring mercury control.

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## LIST OF ABBREVIATIONS AND ACRONYMS

AHPC	advanced hybrid particulate collector
A/C	air-to-cloth
CMM	continuous mercury monitor
DOE	U.S. Department of Energy
EB	eastern bituminous
EERC	Energy & Environmental Research Center
ESP	electrostatic precipitator
FGD	flue gas desulfurization
IAC	iodine-impregnated activated carbon
LOI	loss-on-ignition
NETL	National Energy Technology Laboratory
OH	Ontario Hydro
PJBH	pulse-jet baghouse
PRB	Powder River Basin
PTC	particulate test combustor
PTFE	polytetrafluoroethylene
TDF	tire-derived fuel
WSB	western subbituminous

# MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

## EXECUTIVE SUMMARY

Since 1995, the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) has supported development of a new concept in particulate control called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid*<sup>™</sup> filter by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper.

The objective of this project is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates. The approach includes three levels of testing: 1) bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, 2) pilot-scale testing on a previously proven combustion system with both a pulse-jet baghouse (PJBH) and an AHPC to prove or disprove the research hypotheses, and 3) field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

Initial bench-scale results were in good agreement with previous data. Results showed that the SO<sub>2</sub> and NO<sub>2</sub> concentration effects are additive and have a significant effect on sorbent performance. This finding should facilitate predicting sorbent performance in real systems when the SO<sub>2</sub> and NO<sub>2</sub> concentrations are known.

An initial field test of the 2.5-MW AHPC at the Big Stone Plant was completed the first week of November 2001. Results showed that the average inlet mercury speciation for seven samples was 55.4% particulate bound, 38.1% oxidized, and 6.4% elemental. A carbon injection rate of 24 kg of carbon sorbent/million m<sup>3</sup> of flue gas (1.5 lb of carbon sorbent/million acf) resulted in 91% total mercury collection efficiency, compared to 49% removal for the baseline case.

Following the initial field test, additional bench-scale tests, as well as the first planned pilot-scale tests, were completed. A key finding from the bench-scale tests was that the fixed-bed sorbent-screening tests using simulated flue gas were in good agreement with similar tests sampling real flue gas. This suggests that as long as the main flue gas components are duplicated, the bench-scale fixed-bed tests can be utilized to indicate sorbent performance in larger-scale systems.

In the pilot-scale tests, a baseline comparison was made between the AHPC and a PJBH in terms of the mercury speciation change across the device and the amount of mercury retained by the fly ash. Results showed that for both devices there was very little capture of mercury by the

fly ash. There was some increase in oxidized mercury, but no significant differences were noted between the AHPC and pulse-jet modes of operation.

Even though the same coal was used in the pilot-scale and initial field tests, there was a significant difference in inlet mercury speciation. For the pilot-scale tests, results were more similar to what is typically expected for Powder River Basin (PRB) coals in that most of the mercury was elemental, with little mercury capture by the fly ash. In contrast, for the November 2001 field test, there was much more oxidized than elemental mercury and significant mercury capture by the fly ash. Possible reasons for the difference include higher carbon in the field ash, somewhat higher HCl in the field flue gas due to the cofiring of tire-derived fuel (TFD), possible variation in the coal, cyclone firing for the field compared to pulverized coal firing for the pilot tests, longer residence time for the field tests, and a finer particle size for the field test.

During April–June 2002, a number of baseline and carbon injection tests were completed with Belle Ayr PRB subbituminous coal, one of the coals currently being burned at Big Stone. For the baseline case, approximately 70% of the inlet mercury was elemental, approximately 23% oxidized, and 2% or less was associated with particulate matter. There was very little natural mercury capture across the AHPC for the baseline tests and only a slight increase in the level of oxidized mercury across the AHPC during baseline operation.

With carbon injection, a comparison of short and long residence time in the AHPC showed that somewhat better mercury removal was achieved with longer residence time. No evidence of desorption of mercury from the carbon was seen upon continued exposure to flue gases up to 24 hours. This suggests that desorption of captured mercury from the carbon sorbent is not a significant problem under these flue gas conditions with the low-sulfur subbituminous coal.

At a carbon-to-mercury ratio of 3000:1, from 50% to 71% total mercury was achieved. When the ratio was increased to 6000:1, the removal increased the range to 65%–87%. These results are highly encouraging because this level of control was achieved for the very difficult case with predominantly elemental mercury and very little natural capture of mercury by the fly ash.

A longer-term field test was completed with the 2.5-MW field AHPC August 6 through September 6, 2002. Carbon injection and mercury CMM (continuous mercury monitor) measurements were continuous (24 hours a day) for the entire month except for an unplanned plant outage from August 29 to September 2. The primary goal of the work was to demonstrate longer-term mercury control with the AHPC and evaluate the effect of the carbon injection on the AHPC operational performance. Another goal of the test was to evaluate the effect of supplemental TDF burning on the level of mercury capture for comparison with results from the previous test completed in November 2001.

The inlet mercury speciation during the August 2002 tests averaged 17% particulate bound, 32% oxidized, and 51% elemental. The significant difference in mercury speciation between the August field data and the November 2001 field data is likely the effect of a higher rate of cofiring of TDF with the coal during the November test.

In the November 2001 tests, 49% mercury capture was seen for the baseline conditions without carbon injection. The August tests indicated only 0% to 10% mercury capture with no carbon injection. Again, the most likely explanation is the much higher TDF cofiring rate and higher HCl in the flue gas for the November test.

Addition of activated carbon at a rate of 24 kg of carbon sorbent/million m<sup>3</sup> of flue gas (1.5 lb of carbon sorbent/million acf) resulted in an average of 63% mercury removal in the August tests without any TDF cofiring. A small TDF cofiring rate of about 23 tons per day resulted in an increase in mercury collection to 68%. At the highest TDF rate seen in the August tests of 150–177 tons per day, mercury removal of up to 88% was achieved. This compares with 91% removal seen during the November tests when the TDF feed rate was in the range from 90 to 250 tons per day. These results indicate that TDF cofiring has the effect of increasing the level of mercury control that can be achieved with a low carbon addition rate.

One of the main objectives of the August tests was to assess the effect of carbon injection on longer-term AHPC performance. When the carbon was started on August 7, there was no perceptible change in pressure drop or bag-cleaning interval. Similarly, there was no change in the K<sub>2</sub>C<sub>i</sub> value that relates to how well the ESP portion of the AHPC is working. These results indicate that low addition rates of carbon will have no perceptible effect on the operational performance of the AHPC.

Another short field test was completed with the 2.5-MW AHPC at the Big Stone Plant November 19–22, 2002, to coincide with the first test conducted at the inlet and stack of the full-scale *Advanced Hybrid*<sup>TM</sup> filter after it came on-line October 26, 2002. The primary purpose of the test was to evaluate the effect of injecting a small amount of HCl into the flue gas along with the activated carbon. Results showed that without supplemental HCl injection and a low carbon injection rate of 0.3 kg/hr (1.5 lb/million acf) 65% to over 90% total mercury removal was achieved. This is somewhat better than the results seen in the monthlong continuous test in August 2002. Part of the reason could be the higher temperatures in the AHPC during August, which typically were in the range of 132°–143°C (270°–290°F) compared to 121°C (250°F) for the recent November 2002 tests.

There was little or no effect seen with the supplemental HCl injection. This is somewhat surprising because an extensive amount of bench-scale sorbent work has demonstrated the benefit of HCl for capturing elemental mercury in a simulated flue gas over the temperature range of 107°–188°C (225°–370°F). However, the benefit of additional HCl may be marginal in cases where there is already a sufficient amount of HCl present to achieve good mercury control.

During October–December 2002, A 5.7-m<sup>3</sup>/min (200-acfm) pilot-scale test was also completed with Springfield bituminous coal. The purpose of this test was to evaluate mercury control with the AHPC with a high-sulfur bituminous coal. The Springfield bituminous coal produced a flue gas that was high in all of the acid gases including SO<sub>3</sub>, and most of the inlet mercury was in an oxidized form. A number of short- and longer-term tests with the NORIT Americas Darco FGD carbon at temperatures ranging from 135°–160°C (275°–320°F) showed that this sorbent is completely ineffective at mercury control under these conditions. This is in contrast to the extensive testing conducted previously with the AHPC and subbituminous coal,

where up to 90% mercury capture was seen at a low carbon addition rate. The data are consistent with previous bench-scale testing that has shown that flue gas conditions are critical to the mercury capture ability of an activated carbon.

The previous field studies performed in November 2001 and August 2002 showed there was a correlation between  $\text{Hg}^{2+}$  concentration in the flue gas and the amount of TDF fed into the boiler. However, because of the variability of the TDF feed rate, it was difficult to quantify the TDF effect on mercury removal. This last quarter, a 1-week pilot-scale test was conducted on the 5.7-m<sup>3</sup>/min (200-acfm) EERC AHPC where the coal feed rate and the TDF feed rate were precisely controlled.

Cofiring of TDF with the subbituminous coal had a significant effect on mercury speciation at the inlet to the AHPC. Firing 100% coal resulted in only 19% oxidized mercury at the inlet compared to 47% cofiring 5% TDF (mass basis) and 85% cofiring 10% TDF. The significant increase in oxidized mercury may be partly the result of increased HCl in the flue gas with the TDF. However, since the actual increase of measured HCl was only a few ppm, other changes in combustion conditions or flue gas components may also be responsible for the increase in oxidized mercury.

The TDF not only enhances mercury oxidation in flue gas but also improves mercury capture when combined with FGD carbon injection. With 100% coal, test results have shown from 48% to 78% mercury removal at a relatively low FGD carbon addition rate of 1.5 lb of carbon/million acf. With TDF, results showed from 88% to 95% total mercury removal with the same carbon addition rate while cofiring 5%–10% TDF. These results are consistent with previously reported results from the 2.5-MW pilot-scale AHPC.

W.L. Gore & Associates, Inc., has developed an innovative technology for control of mercury emissions in flue gas streams. Specifically, the configuration involves a mercury control filter placed inside the existing particulate control filter bag, essentially a bag-within-a-bag concept.

During this last quarter, a week of testing was completed with two different cartridge filters on the 5.7-m<sup>3</sup>/min (200-acfm) AHPC. The filters were installed inside of the four cylindrical all-polytetrafluoroethylene (PTFE) bags in the AHPC unit. Operationally, the mercury filter elements did not appear to impair the pulse cleaning of the bags. Initial tests with these cartridges showed that nearly 100% mercury capture could be achieved, but the early breakthrough results were observed. After reviewing these initial results and modification of the material, another week of testing is planned for July or August 2003.

# MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

## 1.0 INTRODUCTION

This project was awarded under U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) Program Solicitation DE-PS26-00NT40769 and specifically addresses Technical Topic Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Plant operated by Otter Tail Power Company, which is hosting the field testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid™* filter by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. In Phase II of the DOE-funded AHPC project, a 2.5-MW-scale AHPC was designed, constructed, installed, and tested at the Big Stone Plant. For Phase III, further testing of an improved version of the 2.5-MW-scale AHPC at the Big Stone Plant was conducted to facilitate commercialization of the AHPC technology. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

## 2.0 EXPERIMENTAL

### 2.1 Objective and Goals

The overall project objective is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates.

Test goals include the following:

- Determine if the bench-scale mercury breakthrough results can be duplicated when real flue gas is sampled.
- Compare the level of mercury control with sorbents under similar conditions at the 55-kW pilot scale between the AHPC and a pulse-jet baghouse.

- Demonstrate 90% mercury capture for both a western subbituminous and an eastern bituminous coal.
- Demonstrate mercury capture with the 2.5-MW AHPC at Big Stone.
- Demonstrate 90% mercury capture over a longer time (3 months) with the 2.5-MW AHPC at Big Stone.

## **2.2 Planned Scope of Work**

To meet the objectives, the work was organized into five tasks:

- Task 1: Project Management, Reporting, and Technology Transfer
- Task 2: Bench-Scale Batch Testing
- Task 3: Pilot-Scale Testing
- Task 4: Field Demonstration Pilot Testing
- Task 5: Facility Removal and Disposition

### ***2.2.1 Task 1 – Project Management, Reporting, and Technology Transfer***

Task 1 includes all of the project management requirements, including planning, coordination among team members, supervision of tests, review of results, meeting attendance, and all aspects of reporting.

### ***2.2.2 Task 2 – Bench-Scale Batch Testing***

The bench-scale tests are for the purposes of verifying previous results, expanding on the SO<sub>2</sub> and NO<sub>2</sub> concentration effect, linking the synthetic gas results to the results with real flue gas, and screening sorbents.

The 30 tests planned with the bench-scale unit are divided into three series that follow a logical progression. The purpose of the first series of tests is to ensure that results obtained by the EERC and others can be duplicated and, second, to include SO<sub>2</sub> and NO<sub>2</sub> as variables. Series 1 tests, shown in Table 1, are intended to verify the previous bench-scale work and expand on the SO<sub>2</sub> and NO<sub>2</sub> concentration effect. In previous work, no tests were completed in which both the SO<sub>2</sub> and NO<sub>2</sub> were reduced at the same time. In all of these tests, the inlet Hg<sup>0</sup> concentration is typically 15 µg/m<sup>3</sup>, and each test is run for approximately 4 hr. The 150 mg of NORIT FGD activated carbon sorbent is equivalent to a sorbent-to-mercury ratio of 3700 after 3 hr of exposure. This concentration has been shown to provide consistent results in previous testing and is sufficient to accurately measure the amount of mercury in the spent sorbent for mass balance closure. The Series 1 tests were previously completed, and results were reported in the January–March 2002 quarterly report.

The second series of bench-scale tests (Table 2) is for the purpose of comparing the bench-scale fixed-bed results sampling real flue gas to those obtained with simulated flue gas for both a

**Table 1. Bench-Scale Series 1 – SO<sub>2</sub> and NO<sub>2</sub> Concentration**

Test No.	Sorbent Type	Temp., °C (°F)	Sorbent Concentration, mg	Flue Gas	SO <sub>2</sub> , ppm	HCl, ppm	NO, ppm	NO <sub>2</sub> , ppm
1	FGD	135 (275)	150	Simulated	1600	50	400	20
2	FGD	135 (275)	150	Simulated	500	50	400	20
3	FGD	135 (275)	150	Simulated	200	50	400	20
4	FGD	135 (275)	150	Simulated	1600	50	400	10
5	FGD	135 (275)	150	Simulated	500	50	400	10
6	FGD	135 (275)	150	Simulated	200	50	400	10
7	FGD	135 (275)	150	Simulated	1600	50	400	5
8	FGD	135 (275)	150	Simulated	500	50	400	5
9	FGD	135 (275)	150	Simulated	200	50	400	5
10	FGD	135 (275)	150	Simulated	Repeat test to be selected			

**Table 2. Bench-Scale Series 2 – Real Flue Gas Comparison**

Test No.	Sorbent Type	Temp., °C (°F)	Sorbent Concentration, mg	Flue Gas	SO <sub>2</sub> , ppm	HCl, ppm	NO, ppm	NO <sub>2</sub> , ppm
11	FGD	135 (275)	150	Real	Flue gas from western coal			
12	FGD	135 (275)	150	Real	Duplicate test of western coal			
13	FGD	135 (275)	150	Simulated*	400	4	300	5
14	FGD	135 (275)	150	Simulated Duplicate*	400	4	300	5
15	FGD	135 (275)	50	Simulated*	400	4	300	5
16	FGD	135 (275)	150	Real	Flue gas from eastern coal			
17	FGD	135 (275)	150	Real	Duplicate test of eastern coal			
18	FGD	135 (275)	150	Simulated*	1000	50	400	10
19	FGD	135 (275)	150	Simulated Duplicate*	1000	50	400	10
20	FGD	135 (275)	50	Simulated*	1000	50	400	10

\* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

western subbituminous (WSB) and an eastern bituminous (EB) coal. The simulated flue gas concentrations are based on the actual concentrations measured in the combustion tests. In addition, tests with lower sorbent concentrations were planned with flue gases matched to the two coals to assist in selecting the best sorbent concentrations for the pilot-scale tests. The real

flue gas tests are part of the first two pilot-scale tests in Task 3, using a slipstream bench-scale system sampling flue gas from the particulate test combustor (PTC).

Tests 11–14 of the Series 2 tests were previously completed, and results were presented in the January–March 2002 quarterly report. Tests 16 and 17 were completed in the October–December 2002 quarter as part of pilot-scale tests with an EB coal. There are no current plans to complete Test 15 because it does not appear that 90% mercury control could be achieved by reducing the carbon concentration from what has already been tested. Tests 18–20 will also not be completed because the pilot-scale tests reported with the bituminous coal showed that the FGD carbon was ineffective at mercury control for the flue gas conditions produced from combustion of this specific bituminous coal.

The third series of bench-scale tests (Table 3) is for the purpose of screening alternative sorbents. The iodine-impregnated activated carbon (IAC) sorbent was initially chosen because of the excellent results seen in some of the previous EERC pilot-scale tests, especially at higher temperatures from 121°–177°C (250°–350°F). IAC also appears to be better at capturing Hg<sup>0</sup> than FGD. However, since IAC is more costly than FGD, it must be effective at lower concentrations than FGD. The plan was to evaluate the IAC for both a subbituminous and a bituminous coal at two concentration levels and two temperatures. However, since pilot-scale tests (reported later in this quarterly report) showed no improvement in mercury removal over the FGD carbon, there is no basis for doing these IAC tests.

**Table 3. Bench-Scale Series 3 – Sorbent Type**

Test No.	Sorbent Type	Temp., °C (°F)	Sorbent Concentration, mg	Flue Gas	SO <sub>2</sub> , ppm	HCl, ppm	NO, ppm	NO <sub>2</sub> , ppm
21	IAC	135 (275)	150	Simulated*	400	4	300	5
22	IAC	135 (275)	50	Simulated*	400	4	300	5
23	IAC	135 (275)	150	Simulated*	1000	50	400	10
24	IAC	135 (275)	50	Simulated*	1000	50	400	10
25	IAC	163 (325)	150	Simulated*	400	4	300	5
26	IAC	163 (325)	150	Simulated*	1000	50	400	10
27	New No. 1 **	135 (275)	150	Simulated*	400	4	300	5
28	New No. 2 **	135 (275)	150	Simulated*	400	4	300	5
29	New No. 3 **	135 (275)	150	Simulated*	400	4	300	5
30	New No. 4 **	135 (275)	150	Simulated*	400	4	300	5

\* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

\*\* New sorbents will be selected based on background data and availability.

The plan was to potentially conduct four additional screening tests on other promising alternative sorbents to be selected based on new information and availability, and then, depending on initial results, further evaluate them in pilot-scale testing in Task 3. Several versions of a non-carbon-based sorbent developed outside the EERC were tested. Initial results showed poor mercury removal which may have been partially due to the preparation and testing procedures, but there are no current plans for further testing of this specific sorbent. The one remaining possible alternative sorbent approach is the cartridge insert idea (explained in more detail in Section 3.2). However, because of the limitation of scale, this will be tested only with the pilot-scale AHPC under Task 3 rather than in the bench-scale system.

### 2.2.3 Task 3 – Pilot-Scale Testing

Six weeks of testing were planned under Task 3. A week of testing includes an 8-hr heatup period on gas and then approximately 100 hr of steady-state operation firing coal. This allows for four 24-hr test periods where the PTC is operated around the clock. The originally planned 6 weeks of tests are shown in Table 4. The first 2 weeks are for the purpose of generating baseline data without carbon injection for a bituminous and a subbituminous coal with both the pulse-jet baghouse (PJBH) and the AHPC. Each test is for a duration of approximately 48 hr. These tests were for the purpose of establishing the amount of mercury capture by fly ash and

**Table 4. Task 3 – Pilot-Scale Testing**

Week/ Test	Purpose	Coal	Collection Device	Sorbent Type	C:Hg Ratio	Injection Method
1-1	Baseline	WSB	PJBH	None	NA <sup>1</sup>	NA
1-2	Baseline	WSB	AHPC	None	NA	NA
2-1	Baseline	EB	PJBH	None	NA	NA
2-2	Baseline	EB	AHPC	None	NA	NA
3-1	Hg capture, collection device	WSB	PJBH	FGD	3000 <sup>2</sup>	Continuous
3-2	Hg capture, collection device	WSB	AHPC	FGD	3000 <sup>2</sup>	Continuous
4-1	Hg capture, residence time	WSB	AHPC	FGD	3000 <sup>2</sup>	Continuous
4-2	Hg capture, residence time	WSB	AHPC	FGD	3000 <sup>2</sup>	Batch
5-1	Hg capture, residence time	EB	AHPC	FGD	3000 <sup>2</sup>	Continuous
5-2	Hg capture, residence time	EB	AHPC	FGD	3000 <sup>2</sup>	Batch
6-1	Sorbent type and concentration	WSB	AHPC	New No. 1 <sup>3</sup>	3000 <sup>2</sup>	Continuous <sup>3</sup>
6-2	Sorbent type and concentration	WSB	AHPC	New No. 1 <sup>3</sup>	1000 <sup>2</sup>	Continuous <sup>3</sup>
6-3	Sorbent type and concentration	WSB	AHPC	New No. 2 <sup>3</sup>	3000 <sup>2</sup>	Continuous <sup>3</sup>
6-4	Sorbent type and concentration	WSB	AHPC	New No. 2 <sup>3</sup>	1000 <sup>2</sup>	Continuous <sup>3</sup>

<sup>1</sup> Not applicable.

<sup>2</sup> Estimated concentrations; actual concentration will be based on previous testing.

<sup>3</sup> To be selected.

determining whether the amount of mercury capture is different between the PJBH and the AHPC. Another purpose was to establish the inlet and outlet speciated mercury concentrations

and whether there was a change in mercury speciation across both devices. A second purpose for these baseline tests was to provide flue gas to support the bench-scale testing with real flue gas under Task 2.

Weeks 3 and 4 were designed to prove the ability of the technology to control mercury at the 90% level with a WSB coal. Week 5 was for testing mercury control in the AHPC with an EB coal.

Week 6 was for the purpose of testing alternative sorbents in the AHPC. The need for alternate sorbent testing is somewhat dependent on the results with the FGD sorbent. If 90% mercury capture was already demonstrated with both coals at a low sorbent concentration (for example, less than 3000:1), then there may be no need to further evaluate other sorbents. In this case, Week 6 would be cancelled, and testing with the field AHPC would proceed. However, if results with the FGD sorbent have not met expectations and other sorbents look more promising or if other unanswered questions remain that could be tested in the pilot tests, Week 6 would be completed.

From the pilot-scale test matrix listed in Table 4, the first 3 weeks of testing with a WSB coal have all been completed (Tests 1-1, 1-2, 3-1, 3-2, 4-1, and 4-2). Results from the first week of testing were reported in the January–March 2002 quarterly report. Results from Weeks 2–4 were presented later in the April–June 2002 quarterly report. The Week 5 test results with an eastern bituminous coal were presented in the October–December 2002 quarterly report. Because no other alternative sorbent was identified, Week 6 of testing was completed this last quarter with the FGD carbon cofiring tire-derived fuel (TDF). In addition to the original plan, two more weeks (Weeks 7 and 8) are planned to evaluate a mercury cartridge insert approach, for a total of eight weeks of tests under Task 3. Initial results from Week 7 are presented in this report. Week 8 testing is planned for July or August 2003.

#### ***2.2.4 Task 4 – Field Demonstration Pilot Testing***

Demonstration of mercury control with the AHPC at the 2.5-MW scale at a utility power plant is the next logical step toward proving the commercial validity of this approach. A total of 5 months of field tests was originally planned. The first month was planned for baseline testing without sorbent injection to establish the mercury concentration, speciation, and amount of fly ash capture as well as to compare mercury emissions at the plant stack with the AHPC outlet.

The second month of field tests was planned for the purpose of establishing the sorbent addition rate to achieve 90% mercury control. Depending on the level of success with the FGD sorbent in the field and the pilot-scale test results with alternative sorbents, the third month was planned for the purpose of evaluating alternative sorbents. If alternative sorbent testing is not done, then 3 months of longer-term testing with the FGD sorbent will be completed. The longer-term operation will establish whether there are any longer-term problems associated with sorbent injection such as bag-cleaning problems. If alternative sorbents are tested during Month 3, then the longer-term demonstration testing will last only 2 months.

According to the planned work, testing with the 2.5-MW AHPC at the Big Stone Plant was not scheduled to begin until after completion of the first pilot-scale tests. However, the project team decided to conduct an initial field test the first week of November 2001 prior to the pilot-scale tests at the EERC.

The field test at Big Stone was completed the week of November 5–10, 2001, with baseline testing on the first day, followed by carbon injection in both AHPC and pulse-jet operational modes for the remainder of the week. The starting carbon addition rate was set at 24 kg of carbon sorbent/million m<sup>3</sup> of flue gas (1.5 lb of carbon sorbent/million acf), with the plan that it could be increased if necessary to achieve good mercury control. However, over 90% mercury control was seen at this carbon addition rate, so no testing was completed at higher carbon concentrations. The results from the November field test were previously reported in the October–December 2001 quarterly report.

An additional month of mercury control testing was completed with the 2.5-MW field AHPC August 6 – September 6, 2002. Carbon injection along with continuous mercury monitor (CMM) measurements was completed during the entire month except during an unplanned plant outage during the period from August 29 to September 2. Those results were presented in the July–September 2002 quarterly report.

During the October–December 2002 quarter, another short-term test was completed with the 2.5-MW AHPC on November 19–22, 2002, to coincide with stack mercury testing for the full-scale *Advanced Hybrid*<sup>™</sup> filter at the Big Stone Plant. Those results were presented in the October–December 2002 quarterly report. One more month of field testing is planned to start in early May and be completed in early June 2003.

#### ***2.2.5 Task 5 – Facility Removal and Disposition***

The field AHPC will be dismantled and removed at the end of this project if no further testing is anticipated in support of subsequent work at the Big Stone Plant. If further testing were to be completed with the field AHPC at another site (funded by possible subsequent projects), the AHPC components would be moved to that site. If no other AHPC testing is anticipated, the salvageable AHPC components will be returned to the EERC, and the larger steel components will be disposed of as scrap steel. The site will then be restored to its original condition. The Big Stone Plant will be responsible for removing the 24-in. ductwork that breeches the plant ductwork, electrical power lines, air supply lines, and communication lines once the project is complete.

### 3.0 RESULTS AND DISCUSSION

#### 3.1 200-acfm Pilot-Scale Tests with Belle Ayr Coal (PTC-BA-636) and Supplemental TDF

The previous field studies performed in November 2001 and August 2002 showed there was a correlation between  $\text{Hg}^{2+}$  concentration in the flue gas and the amount of TDF fed into the boilers. During the start of the August 2002 test at the Big Stone Plant, the tire feed was deliberately stopped to evaluate mercury control with tire feed, showing an overall 63% mercury removal with 0.26 kg/hr FGD carbon injection. When TDF cofiring was started August 12, 2002, at 23 ton/day, much lower than the 90–250-ton/day rate during the November 2001 test, a 68% mercury capture was achieved, suggesting the small rate of TDF cofiring resulted in some improvement in mercury collection. However, because of the variability of the TDF feed rate, it was difficult to quantify the TDF effect on mercury removal. Subsequently, a 1-week pilot-scale test was designed and conducted on the 5.7-m<sup>3</sup>/min (200-acfm) EERC AHPC where the coal feed rate and the TDF feed rate were precisely controlled.

A summary of the test matrix is listed in Table 5.

**Table 5. Summary of the Test Conditions for PTC-BA-636**

Test	Time	Test Conditions	OH and HCl Sampling
1	Feb. 10, 10:24–16:20	Baseline	OH (13:31–14:31) M26 (15:07–16:07)
2	Feb. 10, 16:20–Feb.11, 11:35	1.4 kg/hr (3 lb/hr) TDF	OH <sup>1</sup> (17:44–19:44) OH <sup>2</sup> (9:05–10:05) M26 (10:30–11:30)
3	Feb. 11, 11:47–15:34; 15:49 – Feb. 12, 1:08; 1:18–7:13, 7:21–11:14	1.4 kg/hr (3 lb/hr) TDF + 3000:1 FGD carbon	OH <sup>1</sup> (13:27–15:29) OH <sup>2</sup> (8:57–9:58) M26 (10:20–11:14)
4	Feb. 12, 12:15–13:28, 14:11–17:10	3000:1 FGD carbon	OH (14:28–15:29) M26 (16:00–17:00)
5	Feb. 12, 17:12–18:30, 19:15–23:08, 23:18–Feb. 13, 0:23, 0:43–3:25	2.7 kg/hr (6 lb/hr) TDF + 3000:1 FGD carbon	
6	Feb. 13, 10:16–14:34	2.7 kg/hr (6 lb/hr) TDF, bigger size	OH (11:11–12:11) M26 (12:33–13:33)
7	Feb. 13, 14:35–18:07	2.7 kg/lb (6 lb/hr) TDF + 3000:1 FGD carbon	OH (17:01–18:01)
8	Feb. 13, 18:36–Feb. 14, 8:45	Baseline	
9	Feb. 14, 8:45–13:33	4700:1 IAC carbon	OH (10:01–11:01) M26 (11:26–12:40)

**Test 1 – Baseline.** The coal used in this test was from the Belle Ayr Mine, the same as in previous tests (PTC-BA-628 and 629). Since the general information on the mercury species from the Belle Ayr coal was known, only a 6-hour baseline test was carried out without any carbon or TDF. One pair of OH sampling tests was completed at the AHPC inlet and outlet to establish the mercury species concentrations and determine whether there was a change in mercury speciation across the AHPC unit. The results are shown in Figure 1. At the AHPC inlet, oxidized mercury vapor was  $3.07 \mu\text{g}/\text{m}^3$ , while the elemental mercury vapor was dominant,  $13.14 \mu\text{g}/\text{Nm}^3$ . Mercury associated with particulate was at a very low level of  $0.04 \mu\text{g}/\text{Nm}^3$ , showing little inherent mercury capture by fly ash particles. Because of the excellent fly ash capture efficiency of the AHPC, the particulate-associated mercury was completely removed from the flue gas. The total mercury in the flue gas at the outlet (also shown in Figure 1) was  $12.65 \mu\text{g}/\text{Nm}^3$ , showing a 22.2% mercury capture across the AHPC unit. The total mercury concentration in flue gas at the AHPC inlet was  $16.24 \mu\text{g}/\text{Nm}^3$ , somewhat higher than the  $10 \mu\text{g}/\text{Nm}^3$  measured in the previous tests. The mercury species distributions (shown in Figure 2) in flue gas, however, are quite similar to the results of previous PTC-BA-628 and-629 tests: 75.5%–83.1% of  $\text{Hg}^0$ , 13.7%–22.8% of  $\text{Hg}^{2+}$ , and 0.24%–3.21% of  $\text{Hg}(\text{p})$ , indicating representative and repeatable coal combustion performance was achieved in the PTC tests. At the same time, two CMMs monitored mercury vapor species both at the AHPC inlet and outlet and showed virtually no mercury vapor capture across the system (plotted in Figure 3). This raises the possibility that the first inlet OH measurement was biased high. However, both OH and CMM data showed that a 33%  $\text{Hg}^0$  to  $\text{Hg}^{2+}$  and  $\text{Hg}(\text{p})$  conversion occurred across the filter bags.

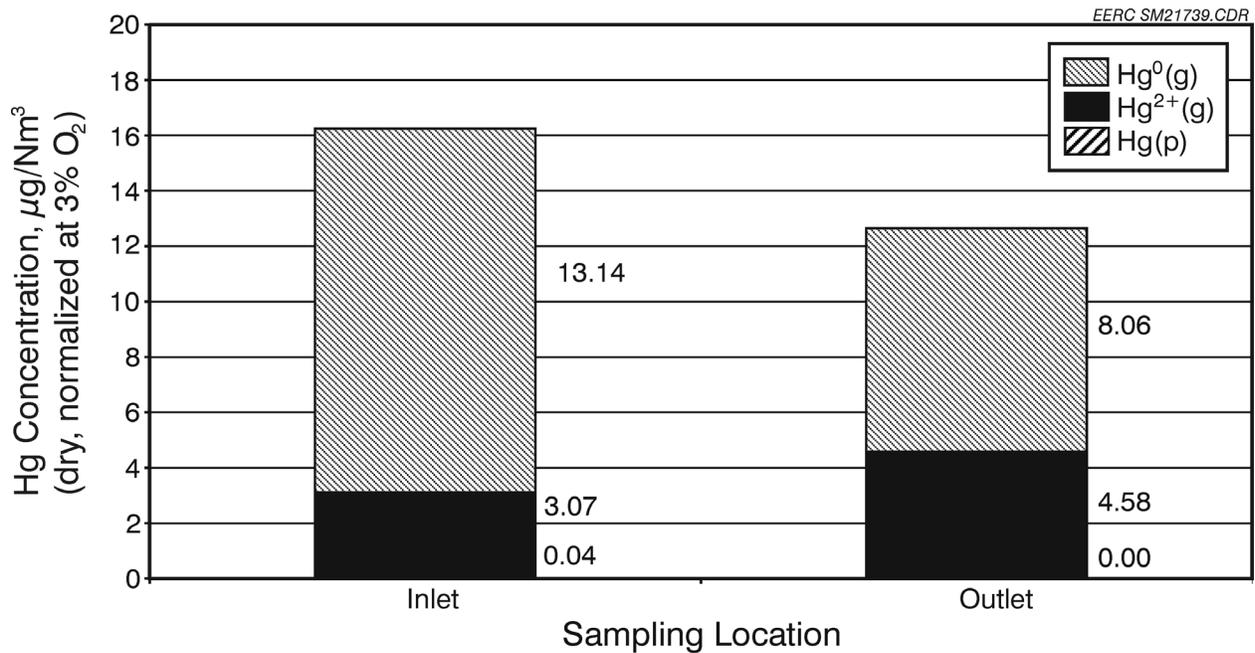


Figure 1. Baseline OH mercury concentration in the flue gas at the AHPC inlet and outlet (PTC-BA-636).

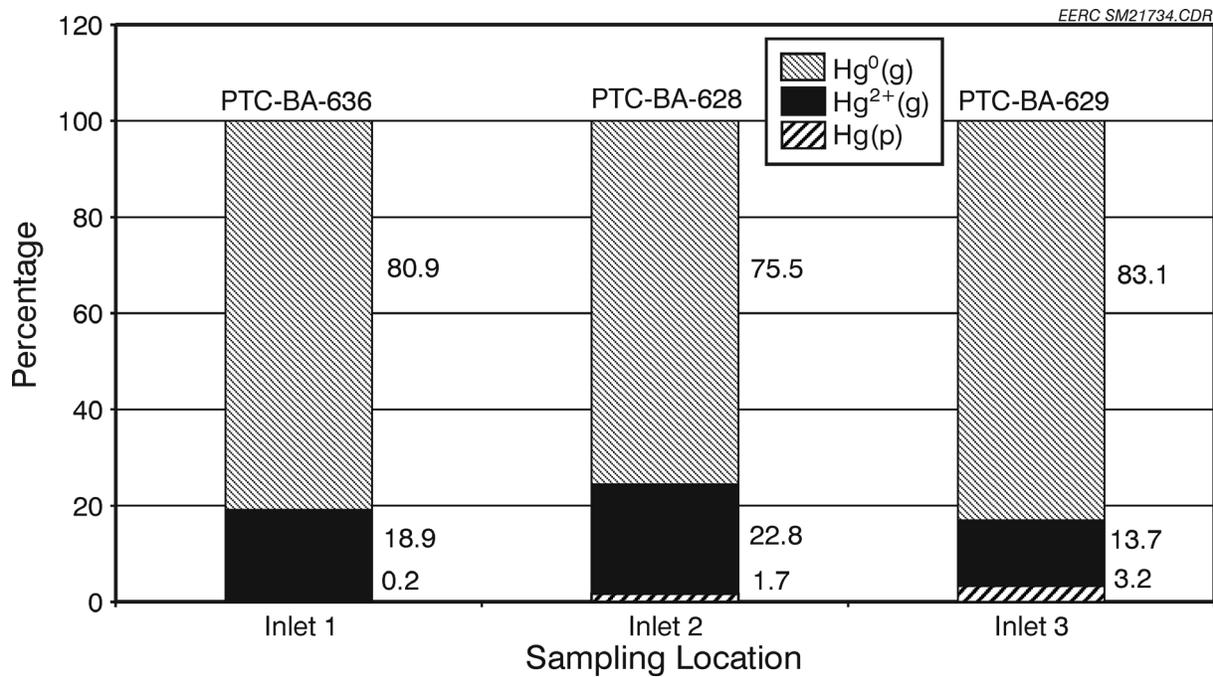


Figure 2. Baseline OH mercury concentration comparisons in Belle Ayr flue gas at the AHPC inlet (PTC-BA-628, 629, and 636).

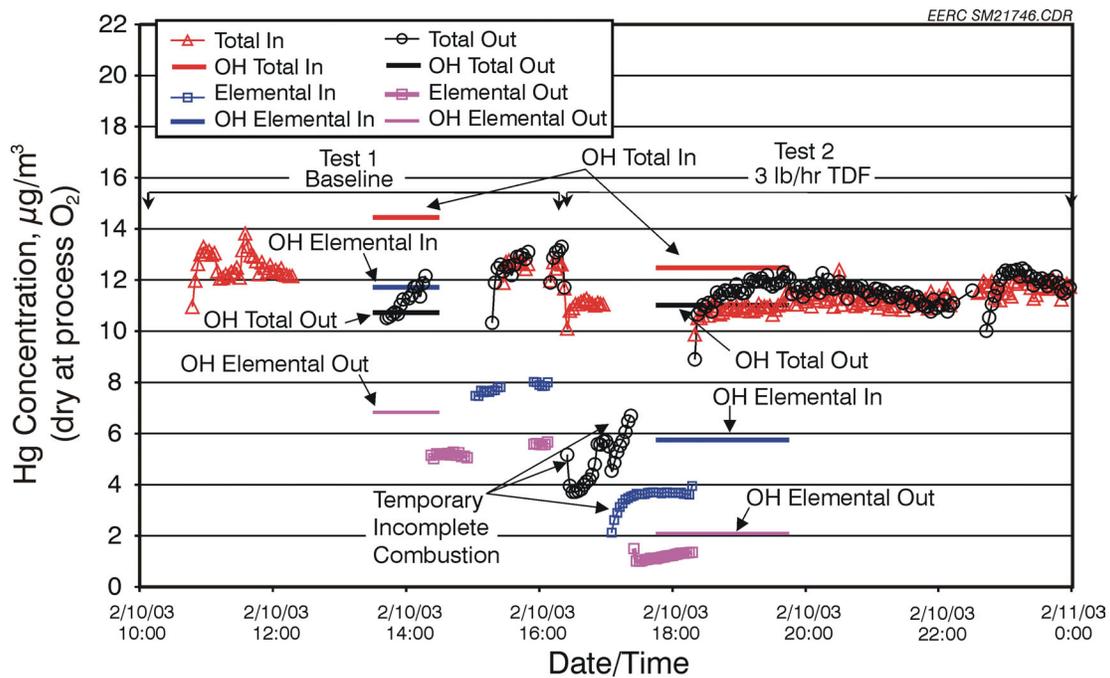


Figure 3. Day 1 – CMM mercury concentration in the flue gas (PTC-BA-636).

**Test 2 – 3 lb/hr TDF.** The TDF is suspected to be the reason for the high levels of particulate-bound and oxidized mercury observed in the November 2001 and August 2002 field tests. The mechanisms, however, are not quite understood and may be attributed to the additional chlorine in the TDF, the unburned carbon from the TDF combustion, or other unknown factors. Therefore, to further confirm and clarify the TDF effect on mercury species in flue gas, Test 2 included the TDF as a supplement fuel at a feed rate of 1.4 kg/hr (3 lb/hr) (corresponding to 5% coal mass-based) to cofire with the Belle Ayr coal. The TDF was preshredded by the supplier to –20 mesh. This material was then screened to –40 mesh at the EERC. The TDF was then fed with a separate feeder directly into the pneumatic coal feed line. The proximate and ultimate analyses for the TDF are shown in Table 6, indicating a high carbon content and heating value. The chlorine in the TDF was also measured and is listed in Table 6. Two OH samples were taken at the AHPC inlet and outlet, and the mercury vapor species across the AHPC unit were monitored by the CMMs. The total mercury concentrations measured by OH at the AHPC unit inlet were in the range of 13–14  $\mu\text{g}/\text{Nm}^3$  (shown in Figure 4), slightly lower than the 16.2  $\mu\text{g}/\text{Nm}^3$  without TDF injection. Part of the reason for lower inlet mercury could be the reduced coal feed rate with supplemental TDF. Both the OH and CMM data showed more mercury in the oxidized state in the flue gas when the TDF was fed into the combustor. At the AHPC inlet, the oxidized mercury vapor  $\text{Hg}^{2+}$  was increased to 47.5% of the total mercury compared to 18.9% without TDF addition, indicating additional oxidation occurred upstream of the AHPC inlet sampling port. At the AHPC outlet, the  $\text{Hg}^{2+}$  accounted for 79.2% of the total mercury emission of 11.88  $\mu\text{g}/\text{Nm}^3$ , and only 20.8% was in the elemental state. The conversion of  $\text{Hg}^0$  to  $\text{Hg}^{2+}$  and  $\text{Hg}(\text{p})$  across the AHPC was 65%, compared to 33% in the baseline test. The mercury emission, nevertheless, was maintained at 12–13  $\mu\text{g}/\text{Nm}^3$ , only a 10%–20% capture efficiency.

**Table 6. Analysis for the TDF**

Proximate Analysis	as received, wt%
Moisture Content	0.6
Volatile Matter	66.22
Fixed Carbon	28.06
Ash	5.12
Ultimate Analysis	
Hydrogen	7.58
Carbon	83.23
Nitrogen	0.80
Sulfur	2.69
Oxygen	0.58
Ash	5.12
Heating Value, Btu/lb	16,485
Cl Concentration in TDF, $\mu\text{g}/\text{g}$ , as received	598

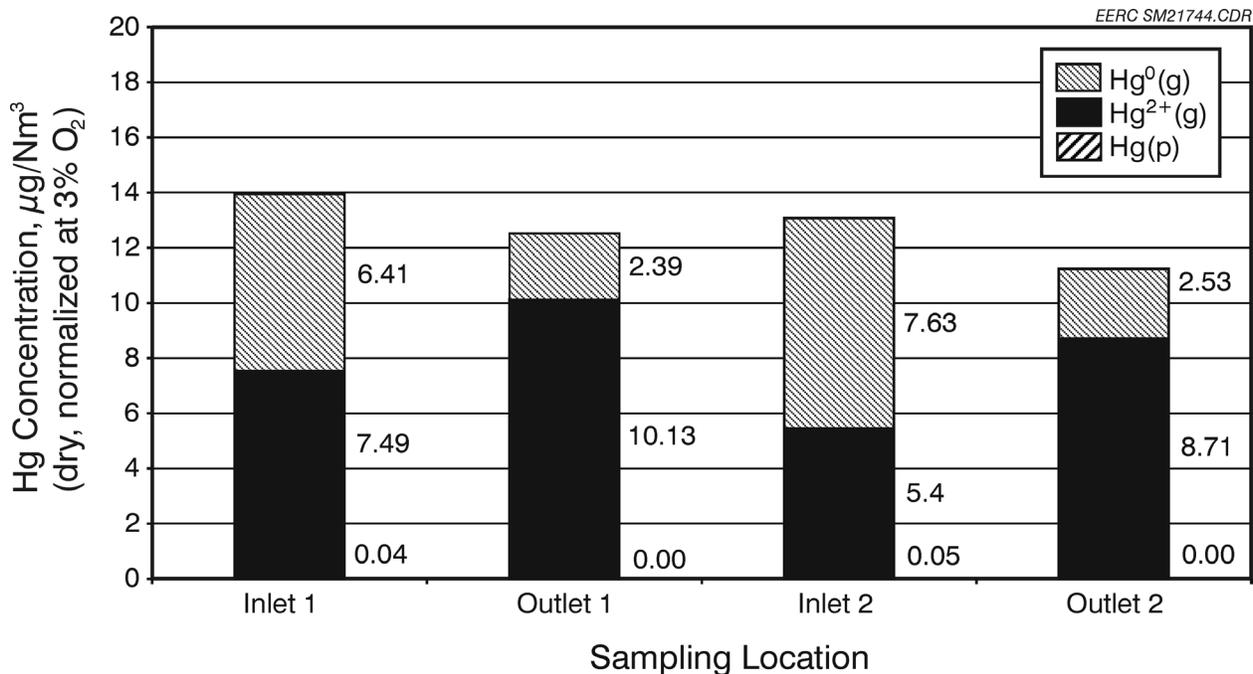


Figure 4. Test 2 – OH mercury concentration in the flue gas at the AHPC inlet and outlet (PTC-BA-636), tire injection rate at 3 lb/hr.

All of the experimental data indicate that TDF enhances mercury oxidation, which may start in the combustion zone and continue in the AHPC unit. One hypothesis is that the high chlorine content in the TDF caused the enhanced oxidation. Method 26 sampling was carried out at the AHPC inlet, showing a HCl concentration in flue gas of 2.54 ppm compared to 0.75 ppm measured in the baseline test (listed in Table 7). The 2.54-ppm HCl in flue gas is still low, but the TDF combustion may enhance the formation of atomic chlorine, which is considered the chlorine species responsible for oxidation.

**Table 7. Chloride Concentrations in Flue Gas, ppmv, dry basis, 3% O<sub>2</sub>**

Baseline	1.4 kg/hr (3 lb/hr) TDF	2.7 kg/hr (6 lb/hr) TDF	1.4 kg/hr (3 lb/hr) TDF + 3000:1 Carbon
0–0.75	2.54	2.47	2.47

In Figure 3, the CMM data show that when TDF addition started, total mercury vapor at the AHPC outlet was temporarily reduced to less than 4 µg/Nm<sup>3</sup>. It took nearly 3 hr to return to the same level as at the inlet concentration. The reasons for the initial mercury reductions are not clear. The flue gas concentrations of O<sub>2</sub>, CO, CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub> during this period are shown in Figure 5. The O<sub>2</sub> concentration was momentarily decreased to 3.5% during 16:20–16:30, with a corresponding CO<sub>2</sub> spike at the combustor outlet, indicating temporarily incomplete fuel combustion when the TDF addition was started. Possibly, unburned carbon was generated and

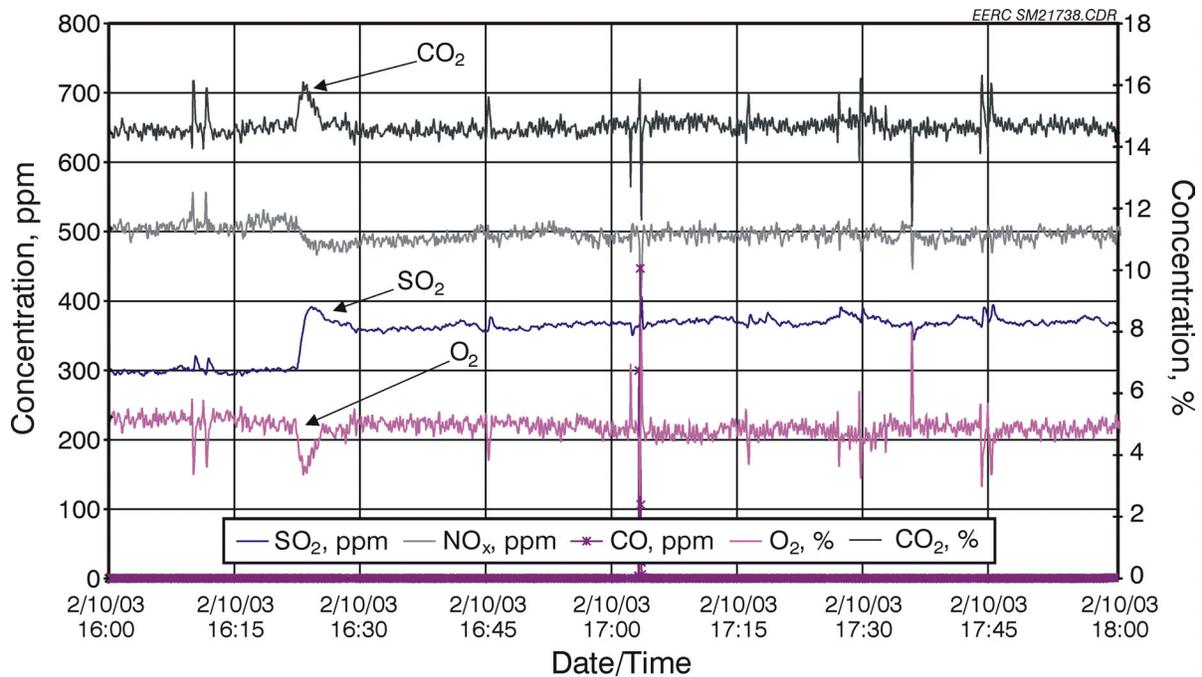


Figure 5. Flue gas history for PTC-BA-636.

attached to the filter bags, where mercury was subsequently captured. More research is necessary to further understand the mechanism.

After an 18-hr test, the hopper ash was collected for loss on ignition (LOI) analysis, and the results (Table 8) are compared to that obtained in the baseline test. The LOI levels in both ash samples are very close: 0.16% and 0.14% for the baseline and 1.4 kg/hr (3 lb/hr) tire addition test, respectively, indicating, in general, good combustion and that there was no significant carbon residue in the ash.

**Table 8. LOI in the AHPC Hopper Ash, %**

	1.4 kg/hr (3 lb/hr)	1.4 kg/hr (3 lb/hr) TDF + 3000:1 Carbon	3000:1 Carbon	2.7 kg/hr (6 lb/hr) TDF + 3000:1 Carbon	2.7 kg/hr (6 lb/hr) TDF	4400:1 IAC
Baseline	0.16	0.14	0.58	0.68	0.77	0.48
						1.31

**Test 3 – 3 lb/hr TDF + 3000:1 FGD Carbon.** With TDF injection, FGD carbon was injected into the system at a carbon-to-mercury ratio of 3000:1, corresponding to 1.54 lb/Macf flue gas. Again, 44.7%–67.4% of the total mercury, based on the OH data shown in Figure 6, had already been oxidized by the TDF upstream of the AHPC unit. After contacting the FGD carbon, the total mercury emission at the AHPC outlet was dramatically decreased to 1.72–1.90  $\mu\text{g}/\text{Nm}^3$

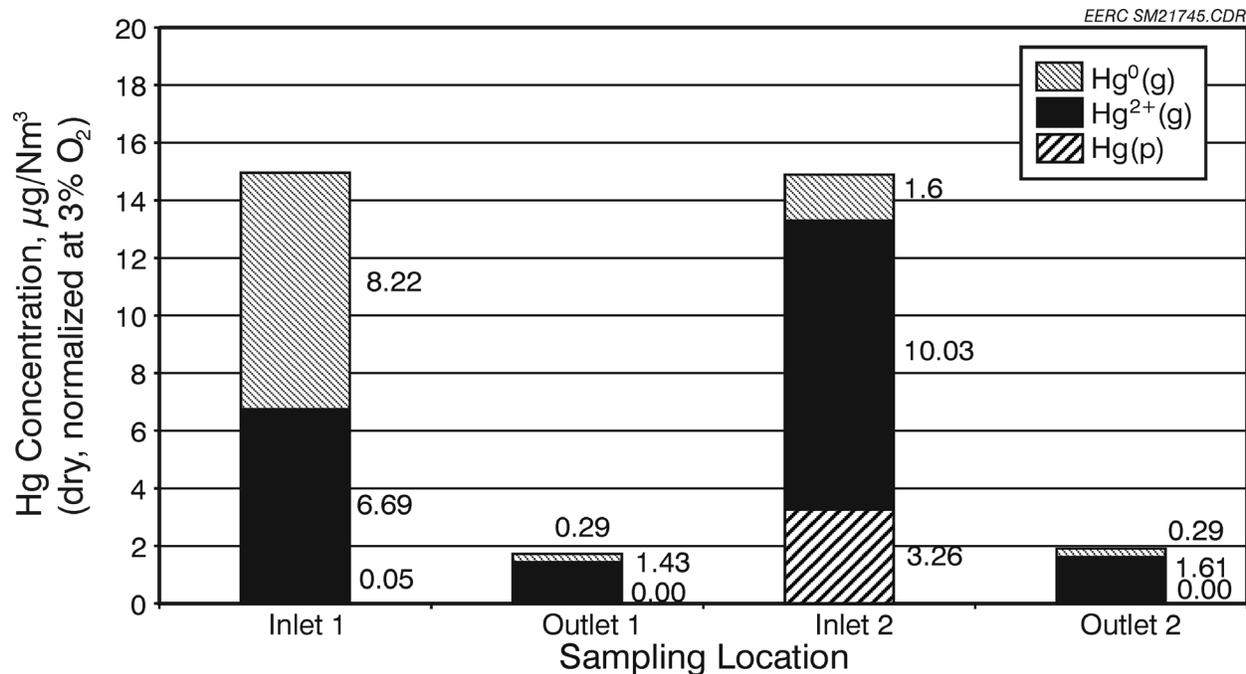


Figure 6. Test 3 – OH mercury concentration in the flue gas at the AHPC inlet and outlet (PTC-BA-636), tire injection rate at 3 lb/hr and carbon injection at 3000:1.

with only 1.43–1.61  $\mu\text{g}/\text{Nm}^3$  of oxidized mercury vapor and virtually no elemental mercury (Figure 6). Total mercury collection efficiency in this test was about 88%.

CMM data in this test are plotted in Figures 7 and 8. Total mercury vapor and elemental mercury vapor concentrations at the AHPC outlet were 1.1–1.9  $\mu\text{g}/\text{Nm}^3$  and 0.07–0.25  $\mu\text{g}/\text{Nm}^3$ , respectively, which matched the OH sampling data. The elemental mercury vapor concentration at the AHPC inlet measured by CMM was somewhat lower than the corresponding OH data, which may be the result of some mercury capture on the sampling filter before the flue gas entered the CMM.

The CMM data also showed, without FGD carbon in the flue gas, that total mercury emission increased (Figure 8), further indicating that TDF is only able to effectively oxidize rather than capture mercury. The 0.58% LOI in hopper ash is higher than that in Tests 1 and 2, which is expected because of FGD carbon injection. The chlorine concentration was 2.47 ppm, the same as the 2.54 ppm in Test 2 since the TDF injection rate was maintained at 1.4 kg/hr (3 lb/hr).

**Test 4 – 3000:1 FGD Carbon.** In order to confirm the improved mercury removal efficiency by carbon injection observed with TDF addition, the TDF was stopped for 5 hours while the FGD carbon was still injected prior to the AHPC. The chloride concentration in the flue gas during this time was virtually zero without TDF injection, according to the Method 26

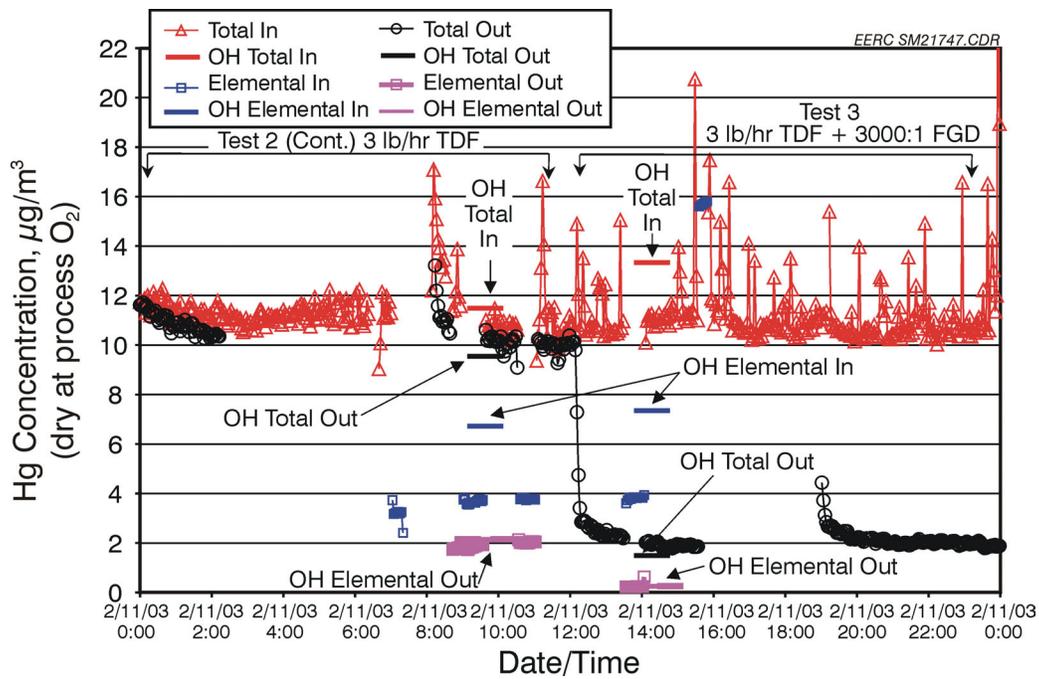


Figure 7. Day 2 – CMM mercury concentration in the flue gas (PTC-BA-636).

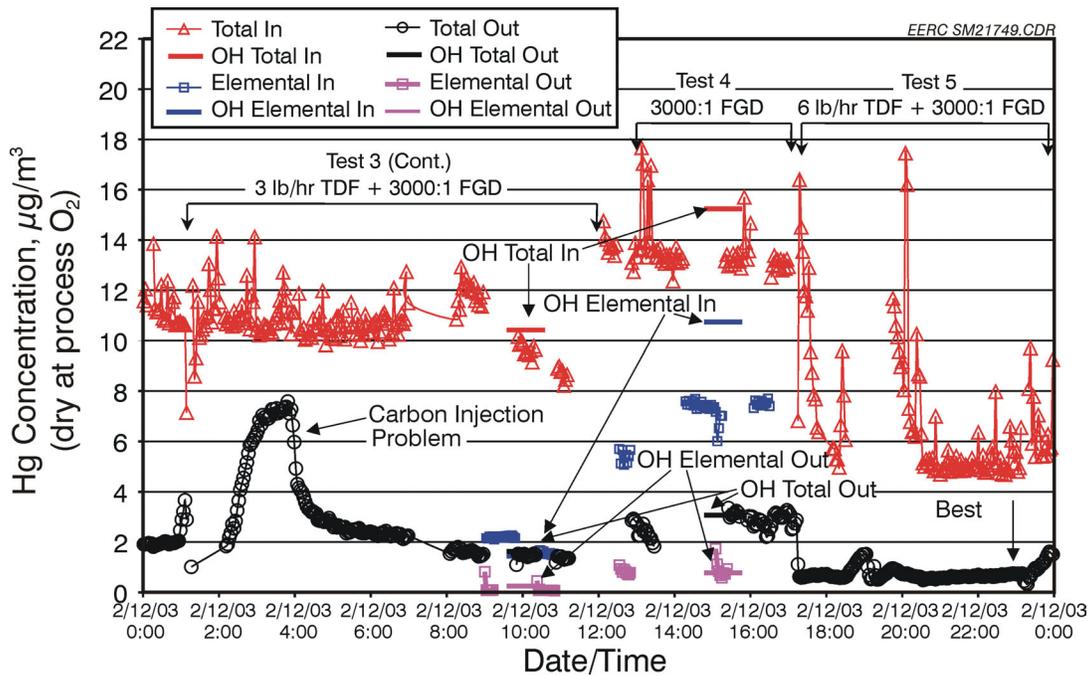


Figure 8. Day 3 – CMM mercury concentration in the flue gas (PTC-BA-636).

data. The CMM data and OH results (Figure 8) showed that the elemental mercury at the AHPC inlet returned to the same level as in the baseline test, accounting for 70% of the total mercury in flue gas. Total mercury emission at the AHPC outlet increased to  $3.78 \mu\text{g}/\text{Nm}^3$  (Figure 9) with no TDF injection. The total mercury removal efficiency was 78%, somewhat higher than the previous data in PTC-BA-628 and -629 tests, although the operating conditions were the same. The flue gas compositions, including  $\text{SO}_2$ ,  $\text{NO}_x$ ,  $\text{O}_2$ ,  $\text{CO}$ , and  $\text{CO}_2$ , were similar during these tests; the only obvious difference was the  $17.3 \mu\text{g}/\text{Nm}^3$  of total mercury present in the flue gas compared to  $10 \mu\text{g}/\text{Nm}^3$  from previous tests. The higher mercury concentration resulted in a greater concentration difference between the mercury vapor in the bulk gas phase and the mercury on the FGD carbon, which may lead to a higher percentage of mercury capture. The conversion of  $\text{Hg}^0$  to  $\text{Hg}^{2+}$  and  $\text{Hg}(\text{p})$  across the AHPC was 93%, almost the same level as that in Test 3 and higher than the 60%–75% in the PTC-BA-628 and -629 tests. It is possible that residual TDF effects caused both higher oxidation and capture. Nevertheless, FGD carbon combined with TDF provided better mercury capture than FGD alone.

**Test 5 – 6 lb/hr TDF + 3000:1 FGD Carbon.** Since more oxidized mercury in flue gas benefits mercury capture by activated carbon, TDF injection was restarted and increased from 1.4 to 2.7 kg/hr (3 to 6 lb/hr). Furthermore, the CMM data (Figures 8 and 10) showed that total mercury vapor at the AHPC inlet during this test temporarily dropped to  $5 \mu\text{g}/\text{Nm}^3$  while the coal feed rate was stable and consistent. The possible reason is that some of the mercury vapor was captured by the particulate matter as a result of the higher TDF feed rate. At the same time, the total mercury emission level at the AHPC outlet was around  $0.6 \mu\text{g}/\text{Nm}^3$ . Since no OH sampling was completed at that time, a total mercury concentration of  $12 \mu\text{g}/\text{Nm}^3$  in flue gas is assumed, corresponding to a capture efficiency of 95%, which is, so far, the best achieved.

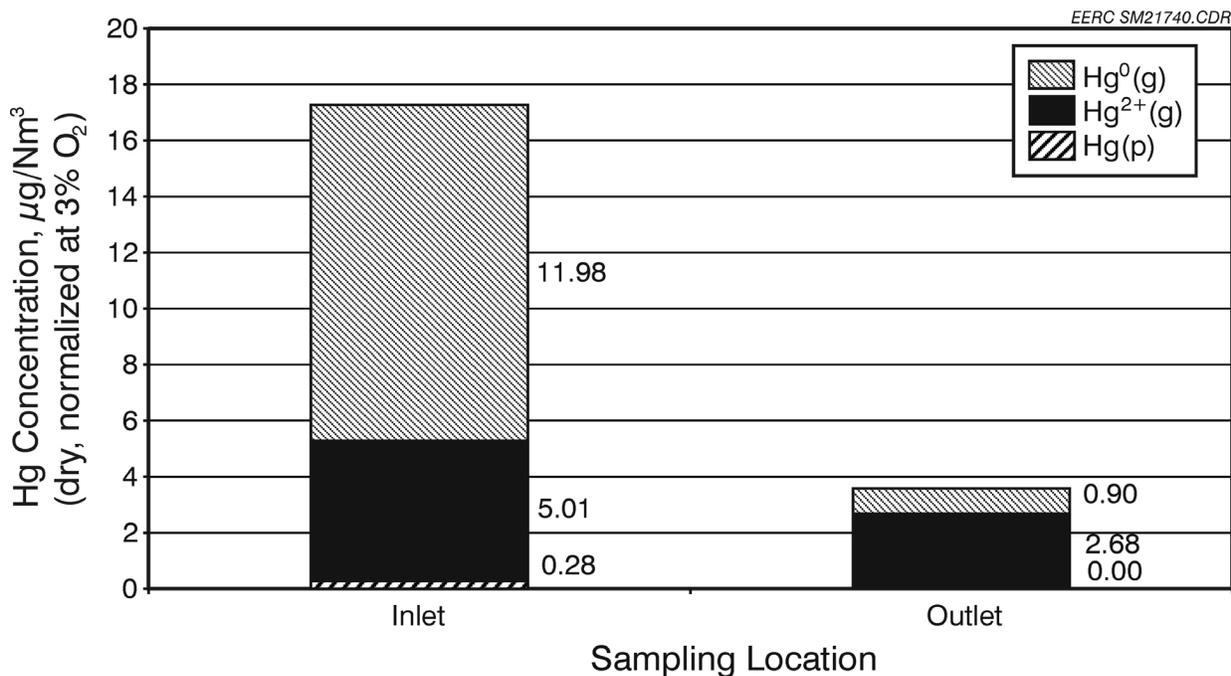


Figure 9. Test 4 – OH mercury concentration in the flue gas at the AHPC inlet and outlet (PTC-BA-636), carbon injection at 3000:1.

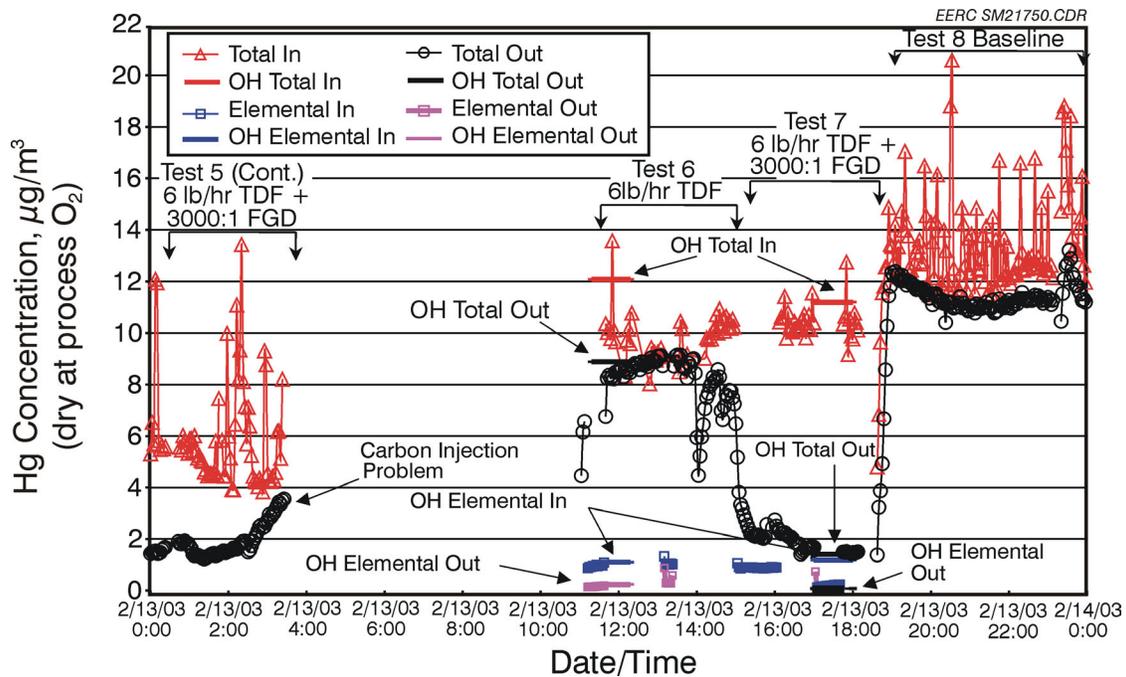


Figure 10. Day 4 – CMM mercury concentration in the flue gas (PTC-BA-636).

**Test 6 – 6 lb/hr TDF, Bigger Size.** The FGD carbon was stopped during this test, while the TDF was still fed at the 6-lb/hr rate. However, the TDF included larger (–20-mesh) material rather than the –40-mesh size TDF for the previous tests. The chloride concentration in the flue gas was 2.48 ppmv compared to zero without TDF injection. The CMM data (Figure 11) show that the mercury vapor concentrations at the AHPC inlet and outlet were the same at 8–9  $\mu\text{g}/\text{Nm}^3$ , and most of the mercury vapor (85%) had already been oxidized by the TDF before it entered the AHPC. The total mercury concentration including the particulate-associated mercury (Figure 12) at the AHPC inlet measured by the OH method was 14.7  $\mu\text{g}/\text{Nm}^3$ , higher than the CMM-determined total mercury vapor concentration value because of the mercury associated with the particulate matter. The mercury capture efficiency was 29.4%, slightly higher than the inherent capture efficiency of 22.1% in the baseline test, showing that the TDF not only enhances mercury vapor oxidation, but also somewhat improves mercury transformation to the particulate phase. The low LOI of 0.48% obtained in this test indicates that the larger-size TDF burned as well as the smaller-size TDF.

**Test 7 – 6 lb/hr TDF + 3000:1 FGD Carbon.** The FGD carbon was restarted at the 3000:1 carbon-to-Hg ratio, and the TDF was kept at 2.7 kg/hr (6 lb/hr). One pair of OH samples was conducted at both the AHPC inlet and outlet. The OH sampling data (Figure 12) at the AHPC inlet showed that the total mercury concentration was around 11.6  $\mu\text{g}/\text{Nm}^3$ , partly because of the decreased coal feed rate. As expected, elemental mercury vapor at the AHPC inlet was significantly decreased to around 1  $\mu\text{g}/\text{Nm}^3$  compared to 4–8  $\mu\text{g}/\text{Nm}^3$  with 3-lb/hr TDF injection, showing that more mercury oxidation occurred. The total mercury emission at the

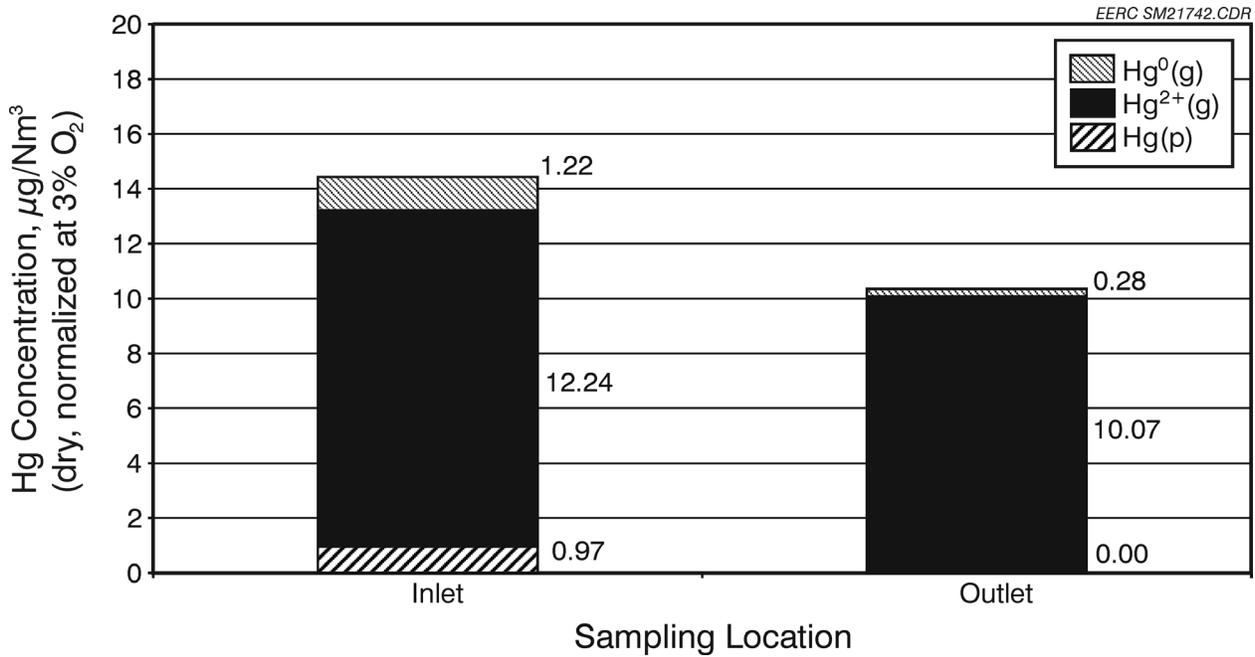


Figure 11. Test 6 – OH mercury concentration in the flue gas at the AHPC inlet and outlet (PTC-BA-636), tire injection rate at 6 lb/hr.

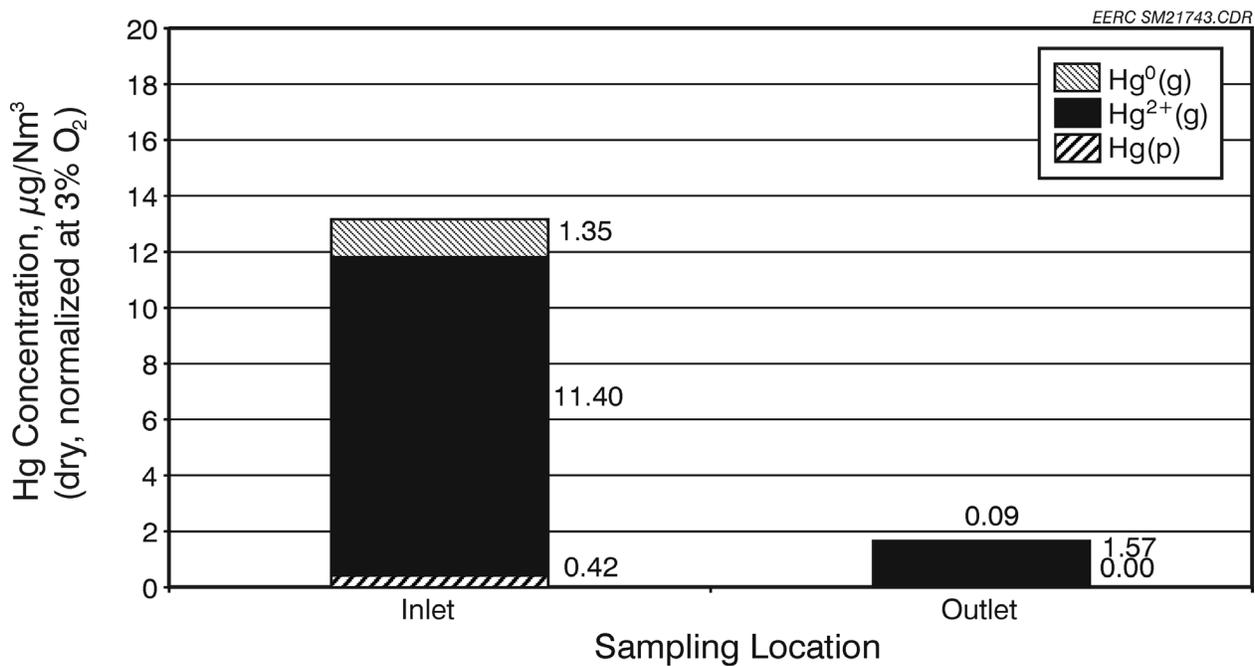


Figure 12. Test 7 – OH mercury concentration in the flue gas at the AHPC inlet and outlet (PTC-BA-636), tire injection rate at 6 lb/hr and carbon injection of 3000:1.

AHPC outlet was  $1.66 \mu\text{g}/\text{m}^3$  (OH results) with  $1.57 \mu\text{g}/\text{m}^3$  of oxidized mercury and virtually no elemental mercury, a total mercury capture efficiency of 87.4%. The OH data indicate no further improvement on mercury removal was achieved by increasing the TDF injection rate.

**Test 8 – Baseline.** Both FGD and TDF were off during this testing period to reestablish baseline conditions. The CMM data (Figures 10 and 13) show the total mercury vapor concentration at the outlet was returned to the same level as the inlet mercury concentration, indicating a fully recovered baseline condition.

**Test 9 – 4700:1 IAC Carbon.** After reestablishing the baseline, an iodine-impregnated carbon (IAC), commercially available from Barnebey and Sutcliffe, was tested in the AHPC unit to examine its ability to remove mercury. Because of the bulk density difference between the FGD carbon and IAC, the actual IAC injection rate was 13.2 g/hr, a carbon-to-mercury ratio of 4400:1. The mercury species at the AHPC inlet (Figure 14) were  $13.2 \mu\text{g}/\text{Nm}^3$  of  $\text{Hg}^0$ ,  $3.23 \mu\text{g}/\text{Nm}^3$  of  $\text{Hg}^{2+}$ , and  $0.04 \mu\text{g}/\text{Nm}^3$  of  $\text{Hg}(\text{p})$ , almost the same as in the baseline tests. At the AHPC outlet, both the CMM and OH experimental data (Figure 13) showed the IAC completely oxidized the mercury. Virtually no elemental mercury exited the AHPC unit when 7–11  $\mu\text{g}/\text{Nm}^3$  elemental mercury, accounting for 60%–80% of the total mercury, entered the AHPC unit. The total mercury emission at the AHPC outlet was still maintained at a relatively high level of  $5 \mu\text{g}/\text{Nm}^3$ , mainly in the oxidized form. The overall mercury capture efficiency was 66.8% based on the OH data, similar to what has previously been achieved with the FGD carbon.

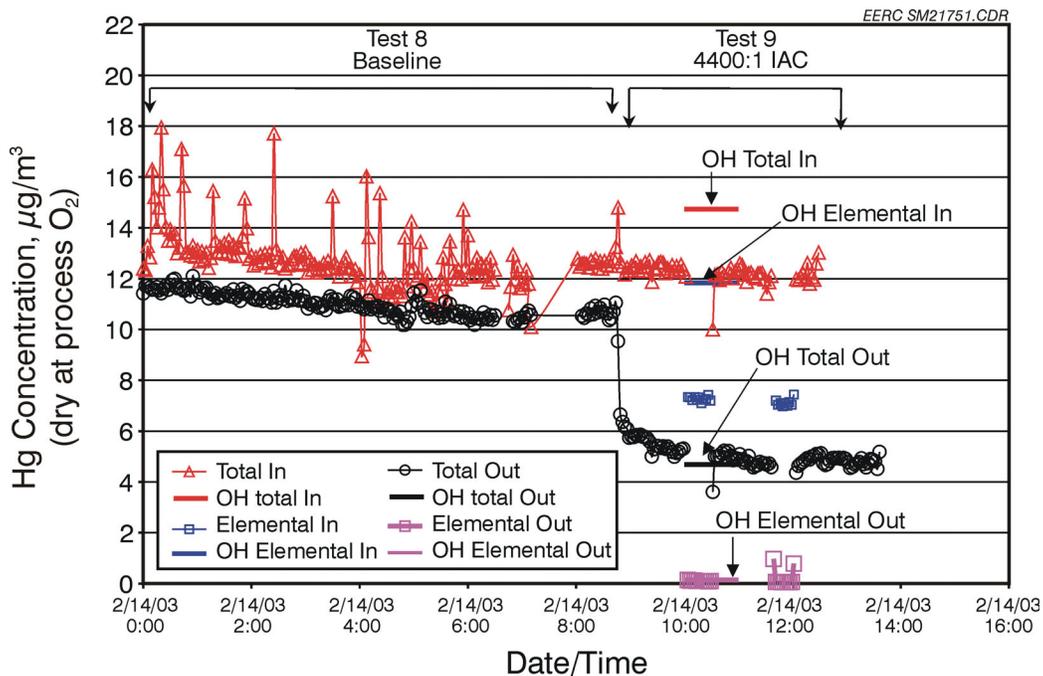


Figure 13. Day 5 – mercury concentration in the flue gas (PTC-BA-636).

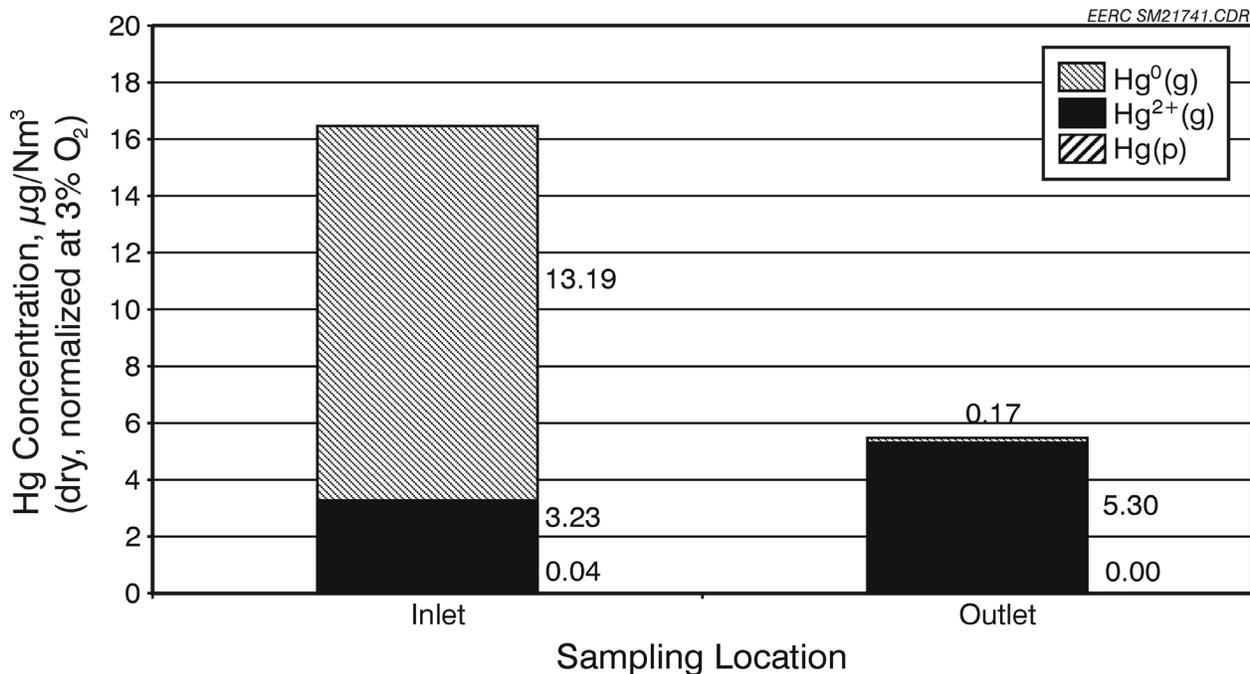


Figure 14. Test 9 – OH mercury concentration in the flue gas at the AHPC inlet and outlet (PTC-BA-636), IAC injection rate at 4400:1.

### 3.1.1 TDF Effect on Carbon Performance for Mercury Capture

A summary of mercury capture efficiency for the tests is plotted in Figure 15. By injecting TDF alone, no significant improvement on mercury removal was achieved, although the TDF effectively enhanced mercury oxidation. Only 28.9% mercury removal was obtained at the 2.7 kg/h (6 lb/hr) TDF addition test compared to 0%–22% inherent mercury capture for baseline tests. For the carbon injection test at 3000:1, since the 78% mercury capture efficiency is suspected to be overestimated, 48.4%–71.2% Hg capture efficiency in PTC-BA-628 and -629 tests is plotted in Figure 15. When FGD and TDF were injected simultaneously, the overall mercury removal efficiency was increased from 88%–95%, showing TDF does benefit mercury capture because of more Hg<sup>2+</sup> in flue gas. The FGD has a better ability to capture Hg<sup>2+</sup> than Hg<sup>0</sup> because the capture process only involves adsorption instead of oxidation and adsorption.

These results are consistent with previous bench-scale tests. The bench-scale data showed the FGD capacity for the Belle Ayr coal flue gas (no tire addition) was about 161 µg/Nm<sup>3</sup>. The capacity of the FGD for different tests is calculated based on the mercury concentrations in the flue gas at the AHPC inlet and outlet and shown in Table 9 for comparison.

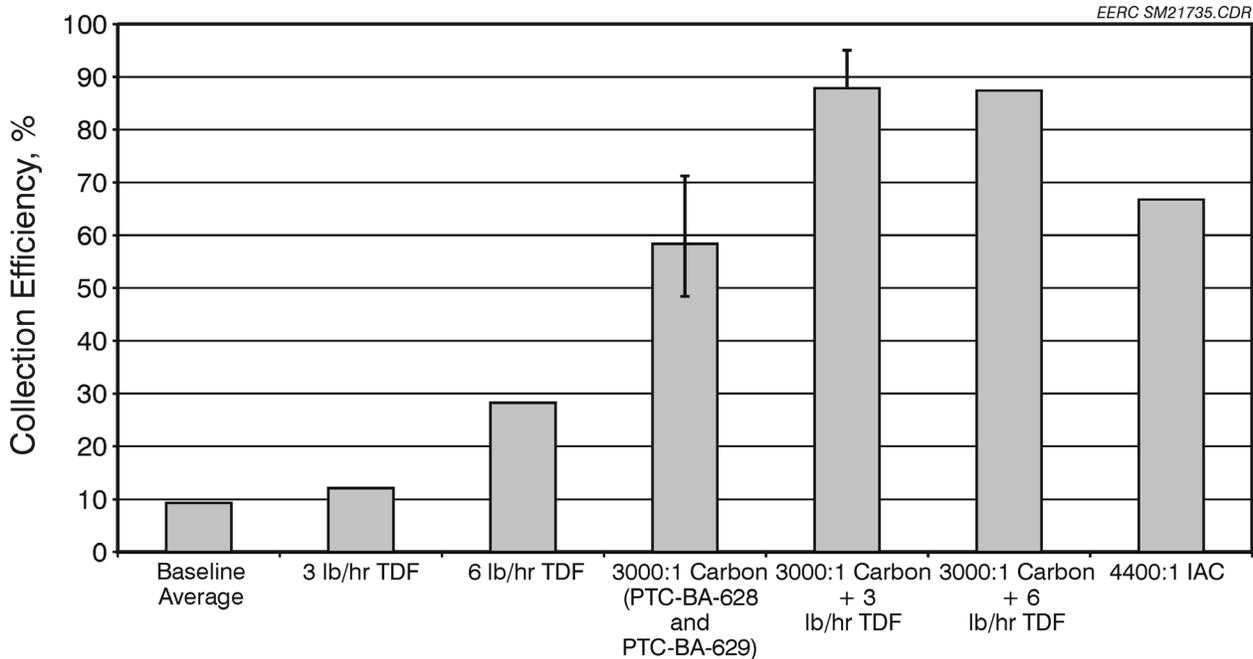


Figure 15. OH results of mercury capture efficiency under different test parameters.

**Table 9. Capacity of FGD Carbon,  $\mu\text{g Hg/g carbon}$**

3000:1 Carbon Injection <sup>2</sup>	3000:1 Carbon + 1.4 kg/hr (3 lb/hr) TDF <sup>2</sup>	3000:1 Carbon + 2.7 kg/hr (6 lb/hr) TDF <sup>2</sup>	Capacity from Bench Scale
125	236	206	161

<sup>1</sup> Results from PTC-BA-628.

<sup>2</sup> 22% inherent mercury capture is considered in calculation.

With the added TDF, much higher capacity was seen compared to the bench-scale test. The TDF not only promotes mercury oxidation but also enhances mercury reactivity with activated carbon, resulting in improved carbon capacity.

### 3.1.2 TDF Effect on Mercury Oxidation

Mercury species distributions at the AHPC inlet are plotted in Figure 16 for the baseline and TDF tests. The data clearly show a significant effect of the TDF on mercury oxidation upstream of the AHPC. The outlet speciation data (Figure 17) show that additional oxidation occurs across the AHPC with the TDF. Almost complete oxidation at the outlet of the AHPC was also seen with the IAC.

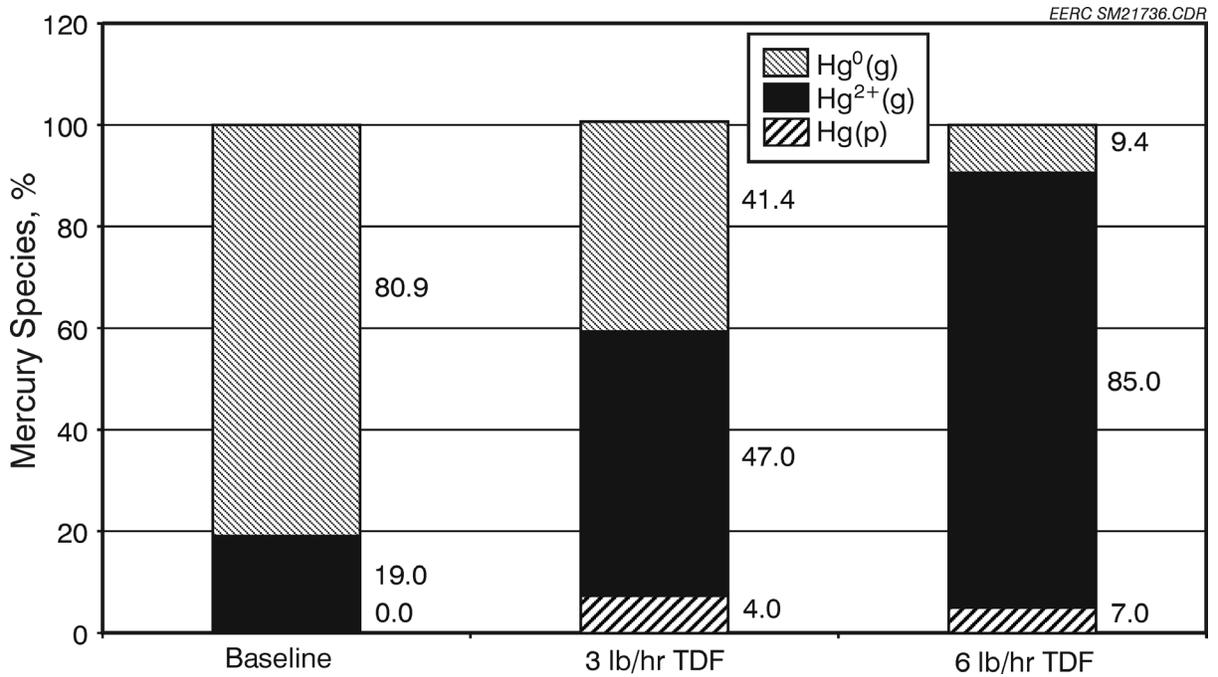


Figure 16. OH results of mercury distributions at the AHPC inlet under different test parameters.

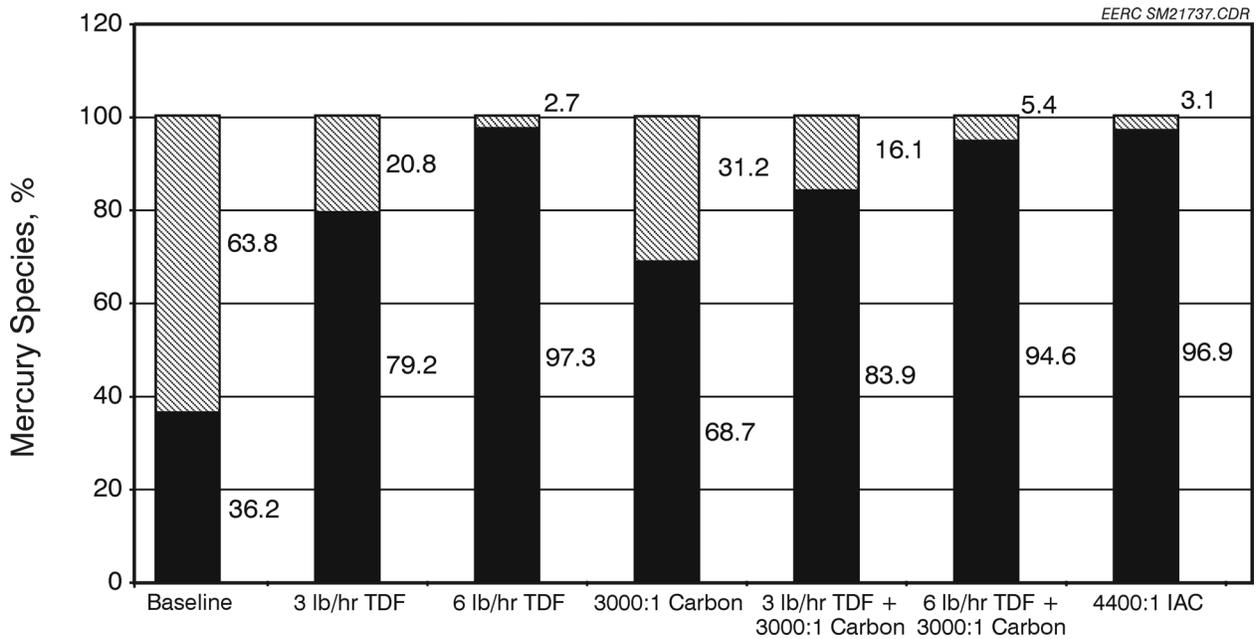


Figure 17. Mercury speciation at the AHPC outlet showing additional mercury oxidation across the AHPC.

### **3.2 200-acfm Pilot-Scale Mercury Cartridge Tests with Belle Ayr Coal (PTC-BA-637)**

W.L. Gore & Associates, Inc., has developed an innovative technology for control of mercury emissions in flue gas streams. Specifically, the configuration involves a mercury control filter placed inside the existing particulate control filter bag, essentially a bag- within-a-bag concept. Prior testing, funded by Gore, at the EPA research facility in Research Triangle Park, North Carolina, has shown significant levels of both elemental and ionic mercury capture.

Over a period of a week, two different cartridge filters (Inserts A and B) were tested separately on the EERC 5.7-m<sup>3</sup>/min (200-acfm) AHPC. The filters were installed inside of the four cylindrical all-PTFE bags in the AHPC unit. Operationally, the mercury filter elements did not appear to impair the pulse cleaning of the bags.

A Tekran CMM was used to monitor the mercury concentrations both at the AHPC inlet and outlet, and OH sampling was also completed to verify the CMM readings. Results showed that initially nearly 100% mercury removal could be achieved. This is an encouraging result because it indicates that there was good contact with the flue gas and filter element and there was no mass transfer limitation. For both filters, higher-than-expected mercury breakthrough occurred earlier than anticipated. Results also showed that the mercury removal was dependent on temperature.

After reviewing these initial results and modification of the material, another week of testing is planned for July or August 2003. After completing the second week of tests, those results along with more details of the first week's results will be reported.

## **4.0 CONCLUSIONS**

- Cofiring of TDF with the subbituminous coal had a significant effect on the mercury speciation at the inlet to the AHPC. Firing 100% coal, there was only 19% oxidized mercury at the inlet compared to 47% cofiring 5% TDF (mass basis) and 85% cofiring 10% TDF. The significant increase in oxidized mercury may be partly the result of increased HCl in the flue gas with the TDF. However, since the actual increase of measured HCl was only a few ppm, other changes in combustion conditions or flue gas components may also be responsible for the increase in oxidized mercury.
- The TDF not only enhances mercury oxidation in flue gas but also improves mercury capture when combined with FGD carbon injection. With 100% coal, test results have shown from 48% to 78% mercury removal at a relatively low FGD carbon addition rate of 1.5 lb of carbon/million acf. With TDF, results showed from 88% to 95% total mercury removal with the same carbon addition rate while cofiring 5%–10% TDF. These results are consistent with previously reported results from the 2.5-MW pilot-scale AHPC.
- The IAC provided no better mercury removal than the FGD carbon. However, with the IAC, a larger fraction of mercury was oxidized across the AHPC. This suggests that the IAC

effectiveness is also highly dependent on flue gas conditions, similar to the FGD. The mechanisms of oxidation and capture for the two carbons may be different, but, the exact conditions where the IAC may provide better mercury control than the FGD carbon are not known.

- A promising alternative sorbent approach for mercury control is to incorporate the sorbent into a cartridge that can be placed inside the filter bags. Initial tests with these cartridges showed that nearly 100% mercury capture could be achieved, but the early breakthrough results suggest that further testing is needed.